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EFFECTS OF VENT HOLES ON STRENGTH OF FIBERBOARD BOXES AND FRUIT COOLING RATE

Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This report, covering research of a continuing nature, is partly based on previous research on the cooling of apples in various containers and the stacking arrangement of the containers in cold storage houses. It discusses the effect of holes in the ends of the box on the strength of a commercial fiberboard box. It also covers the cooling rate of apples packed in these containers and in the same containers without ventilating holes.

This research was conducted at the Wenatchee, Wash., field office of the Transportation and Facilities Research Division, Agricultural Research Service. Joseph F. Herrick, Jr., Investigations Leader, Handling and Facilities Research Branch, supervised the research.

The author wishes to acknowledge the assistance and consultation offered by H. A. Schomer and Kenneth L. Olsen, Market Quality Research Division, Agricultural Research Service, Wenatchee, Wash., by Professor E. F. Cross in making the compression tests, and by Walla Walla College.

EFFECTS OF VENT HOLES ON STRENGTH OF FIBERBOARD BOXES AND FRUIT COOLING RATE

By Glenn O. Patchen, mechanical engineer
Transportation and Facilities Research Division
Agricultural Research Service

SUMMARY

This study is a continuation of the cooling research by Olsen, Patchen, and Schomer. [1] In this study we used compression tests to determine the strength of fiberboard boxes.

The strength of the boxes was affected very little as long as the vent holes were in the unstressed area away from the box corners. Most of the strength of the boxes is in the formed corners, where the angle formation limits bending.

Half-cooling time was shortest for the box with the largest holes. It was only 14.8 hours compared with 33.2 hours for a standard fiberboard box without ventilation holes.

DESCRIPTION OF FIBERBOARD BOXES

Twelve standard telescoping boxes made of fiberboard were used. After they were formed, the "G" boxes were glued in a standard packing line glue machine and the "S" boxes were stapled. In the compression tests, both stapled and glued boxes were used; in the cooling tests, only stapled boxes were used. Vent holes of various sizes and arrangements were cut in the ends (not the sides) of 10 of the boxes; no holes were cut in the two check boxes, 1-G and 1-S (fig. 1).

Holes were cut in each box as follows:

Box 1-G (check): none
Box 2-G: two holes in each end, as used commercially; each hole
      1/2 by 1 1/2 inches
Box 3-G: two holes in each end; each hole 1 by 1 1/4 inches
Box 4-G: two holes in each end; each hole 1 by 2 1/2 inches

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1/ Olsen, Kenneth L., Patchen, Glenn O., and Schomer, Harold A. Cooling Rates of Apples Packed in Fiberboard Boxes as Influenced by Vents, Perforated Trays and Stacking Pattern. Proc. Wash. State Hort. Assoc. 56: 214-220. 1960

Box 5-G: same as 3-G with a third hole 1 by 2 1/2 inches in
          center of each end
Box 6-G: four holes in each end: one oblong slot (handhole)
          1 by 4 inches with rounded ends, center 1 1/2 inches
          from top of box; three round holes 2 inches in diameter,
          one in center and one in each lower corner 3 1/2 inches
          from side and 1 1/2 inches from bottom of box

The stapled boxes have the same holes cut in them as the glued boxes
have and are labeled 1-S through 6-S.
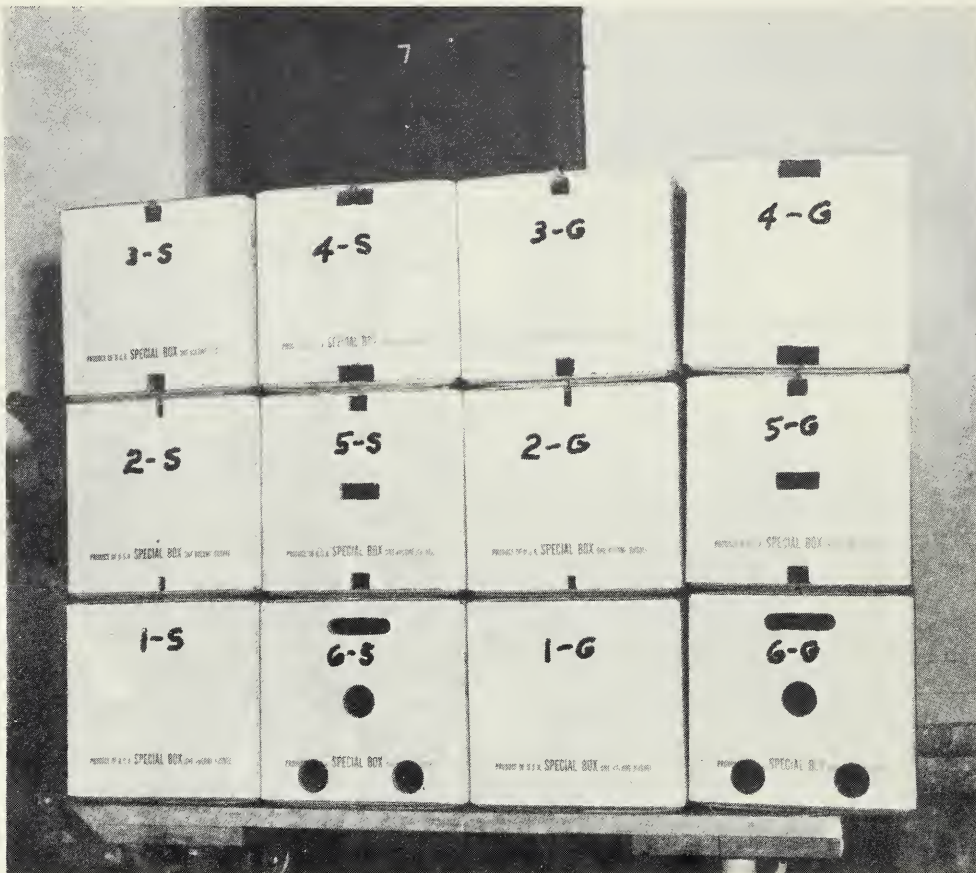
Figure 1.--Fiberboard boxes used in the tests, showing
locations of holes and box number.

A Tinneus Olsen compression machine was used to determine the compressive strength of the boxes. [2] It was hydraulically operated and had a compression range of 0 to 60,000 pounds. The boxes were placed in the testing machine with a 3-inch compressive plate of laminated plywood above and below the box to distribute the applied pressure evenly (fig.2).
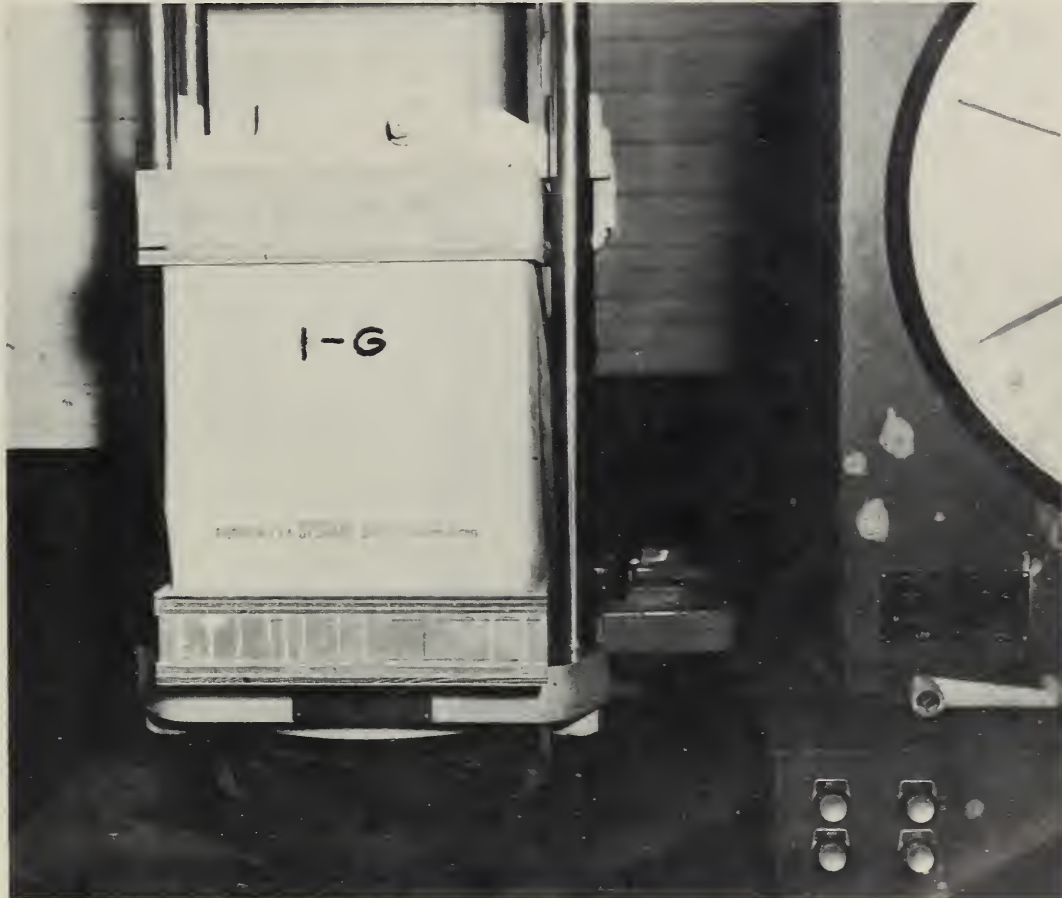
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Figure 2.--Fiberboard box No. 1-G in Tinneus Olsen compression machine after compression failure. Note the laminated plywood blocks above and below the box used to distribute the compressive load.

Table 1 shows the compression strength of the boxes and indicates their percentage of relative strength compared to the fiberboard box without holes that has an index of 100.

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    [2] The tests were run on equipment at Walla Walla College, Walla Walla, Wash.

TABLE 1.--Compressive strength of dry fiberboard boxes with various
shapes and sizes of vent holes

Box No.	Compressive strength	Strength index [1]	Box No.	Compressive strength	Strength index [1]
	Pounds	Percent		Pounds	Percent
1-G(Check)	3,270	100.0	1-S(Check)	2,970	100.0
2-G	2,760	84.6	2-S	3,120	105.0
3-G	2,690	82.3	3-S	2,830	95.4
4-G	2,580	79.0	4-S	2,860	96.3
5-G	2,820	86.3	5-S	2,940	99.0
6-G	2,590	79.2	6-S	2,810	94.6

[1] Check = 100

The glued boxes had a strength variation of 21 percent while the stapled boxes
had a strength variation of only 5 percent, as shown in this table.

Most of the vertical strength of fiberboard boxes is in their corners,
so that vents near the corners reduce the box strength much more than those
near the centers of the sides or ends. C. C. Peters and K. Q. Kellicutt [3]
made the following statements about their compressive tests on fiberboard
boxes:

"1. When areas are removed from the panels of a box for the
purpose of providing ventilation or handholes, the reduc-
tion in box compressive strength usually did not exceed
10 percent when the amount of area removed was in accord-
ance with the carrier regulations.

"2. Reductions in strength were greatest when material was re-
moved from areas of concentrated stress, usually extending
diagonally from the corners, and when material was removed
from areas too close to the horizontal and vertical edges
of the box.

[3] Peters, C. C., and Kellicutt, K. Q. Effect of Ventilating and
Hand Holes on Compression Strength of Fiberboard Boxes. Forest Products
Laboratory, Forest Serv., USDA, Madison, Wis. No. 2152, Aug. 1959.

"3. The location of cutout areas is more significant than the amount of material removed, as shown by the fact that removal of 3.6 percent of an area caused a reduction in strength of 22.5 percent, while in another instance as much as 24.8 percent of the panel area was removed with about the same reduction in strength."

COOLING RATE STUDIES

The same boxes used in the compression tests were used in the cooling rate studies. One cooling test was run on each box and on a standard unvented box.

Previous studies [4] indicated that reused test apples required a slightly longer time to cool. To avoid this difficulty and remove this variable, thermocouples were inserted into plastic balls filled with water. Each ball was 2 3/4 inches in diameter. The plastic balls were placed in the bottom, middle, and top trays of the boxes as shown in figure 3. Thermocouples were also used at locations within and outside the boxes to record the air temperature. The thermocouples were extended to a multipoint recording potentiometer capable of recording the temperatures from 32 different thermocouple positions (16 in test box and 16 in check box), and the temperature of each thermocouple was recorded once every 32 minutes.

The air circulation paralleled the ends of the boxes. The test box was located in the center of a stack of nine fiberboard boxes filled with apples as shown in figure 4. The check box was in the same position in the other stack. Perforated fiberboard trays were used in all boxes, except as noted in table 2. Tray pockets that did not contain water-filled plastic balls contained size 100 apples. All fruit was left unwrapped. Before each test, the boxes were held in a room heated to 70° F. until they reached a uniform temperature.

The boxes of apples were stacked in two rows on pallets in a test room. One row contained the check box (a standard fiberboard box without vents) and the other row contained the test box (fig. 4). The two rows were about 6 inches apart and parallel to each other. Their positions in the room were marked so that each succeeding test could be located in the same place.

As shown in figure 4, the test boxes were placed so that each one was completely surrounded by boxes filled with apples. Only the ends of the test boxes were exposed to direct airflow.
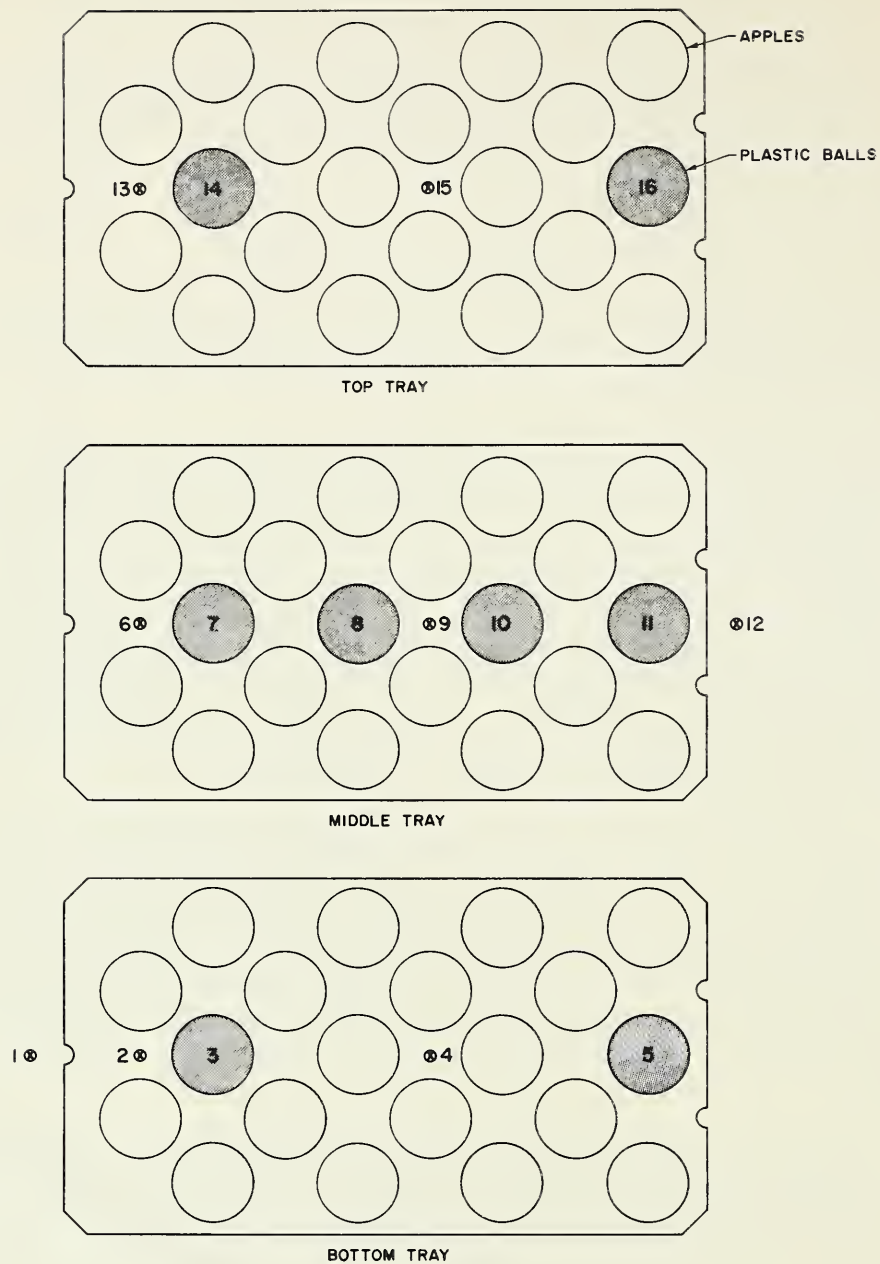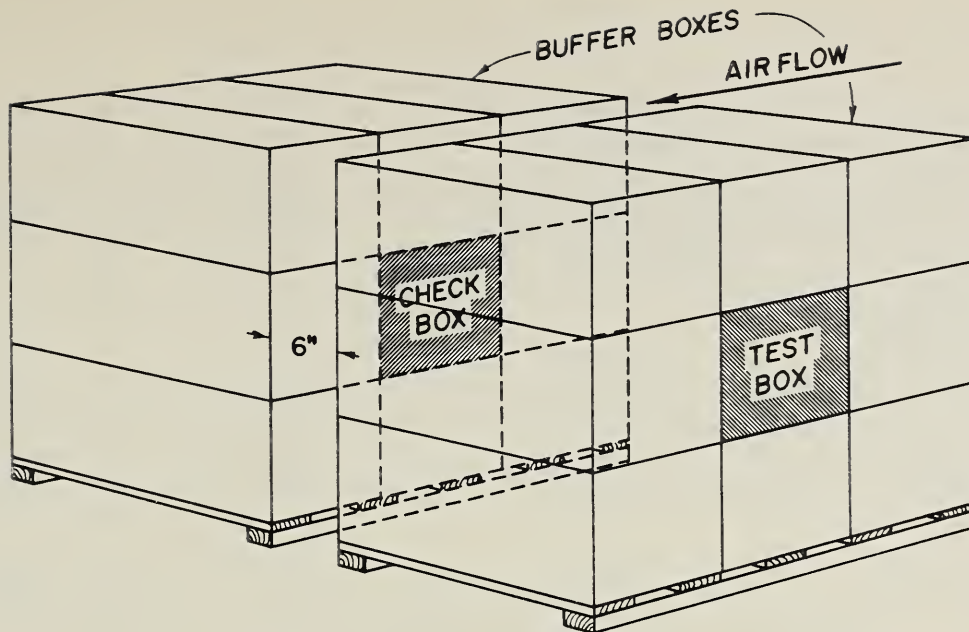
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[4] See footnote 1.

Figure 3.--Location of thermocouples and plastic balls by number in top, middle, and bottom trays of fiberboard test boxes. Those marked ⊗ indicate thermocouple positions for recording air temperature.

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Figure 4.--A group of nine fiberboard boxes showing the locations of the test box surrounded by filled boxes, and the direction of airflow past the ends of the boxes.

CALCULATION OF COOLING RATE

The temperature of the two plastic balls in the center of each box was recorded throughout the test. These records were analyzed and a cooling period was selected. The period started when the first sustained reduction in temperature was noted (about 5 hours after the test began) and ended 45 hours later. The average temperature of the plastic balls was determined from data obtained during each of the nine 5-hour segments of the test period. The change in the average temperature of the plastic balls then was determined for the total test period. Corresponding average ambient air temperature was determined in the same way.

TABLE 2.--Cooling data for plastic balls in fiberboard or plastic
trays, using stapled boxes

Test box	Cooling coefficient (C)	Half-cooling time (Z)	Index
	$\dfrac{^{\circ}\text{F.}}{(\text{Hr.})(T_{pb} - T_a)}$	Hr.	Pct.
Perforated fiber-board trays:			
1-S Check	0.0223	31.2	100.0
2-S	.0240	28.8	92.3
1-S Check	.0190	36.4	100.0
3-S	.0238	29.1	80.0
1-S Check	.0204	34.0	100.0
4-S	.0254	27.3	80.3
1-S Check	.0249	27.8	100.0
5-S	.0266	26.0	93.0
1-S Check	.0209	33.2	100.0
6-S	.0468	14.8	44.5
Nonperforated plastic trays:			
1-S Check	.0203	34.1	100.0
3-S	.0201	34.6	101.5

The cooling coefficient, C, for each test was calculated using the
formula:

$$C = \frac{\text{Temperature change } ^{\circ}\text{F.}}{/\overline{\text{Hours in period}}/ \ /\overline{\text{Average temperature of plastic balls - average air temperature}}/}$$

The cooling coefficient, C, was calculated for each test box and con-
verted to half-cooling time, Z, using the following formula:

$$Z \text{ (hours)} = \frac{\log_e \frac{1}{2}}{C}$$

Half-cooling time, Z, is the time required for the water-filled plastic balls
to cool to a temperature half-way between the initial temperature of the balls
and the air temperature, assuming a constant air temperature.

This approximates the time required for the removal of one-half of the
field heat from apples. A period of 2Z is required to remove three-fourths of
the field heat; a period of 3Z to remove seven-eighths of the field heat. [5]

5/ Patchen, G. O. and Sainsbury, G. F. Cooling Apples in Pallet Boxes.
U.S. Dept. Agr. Mktg. Res. Rpt. No. 532, Aug. 1962.

The cooling coefficients and half-cooling times for the boxes tested are shown in table 2.

The general commercial practice has been to provide a container for apples that allows them to cool quickly and has sufficient strength to resist storage and shipping stresses. Table 2 shows that box 6-S had the shortest half-cooling time, only 14.8 hours, compared with 33.2 hours for the standard fiberboard box. Box 6-S had 5 percent less strength than the standard fiberboard box (table 1). All the strength tests were comparable to those reported by C. C. Peters and K. Q. Kellicutt. [6]

The half-cooling time for the different boxes tested indicates a variable rate of cooling (table 2). Although the half-cooling time for box 6-S was the fastest, subsequent tests by Schomer and Patchen [7] indicate that any of the boxes would be satisfactory for the cold storage of apples. They tested three lots of apples:

1. Hydrocooled to a core temperature of 40° F.
2. Air cooled to a core temperature of 35° F. in 3 days.
3. Air cooled to a core temperature of 35° F. in 7 days.

All lots were then stored at 30° to 31° F. All three lots had approximately the same storage life expectancy and dessert quality.

A cooling time of 3Z would be required to remove seven-eighths of the field heat from a box of apples. Based on the slowest half-cooling time, Z, (table 2) this would amount to 36.4 x 3 = 109.2 hours, which is approximately 69 percent of a 7-day period, a very satisfactory cooling time.

Half-cooling time showed some increase in a cooling test using plastic trays, but in this test the fruit had been used a number of times and the trays were not perforated. These factors would increase the half-cooling time (table 2). As before, 3Z (3 x 34.6 hours = 103.8 hours) would indicate a very good cooling rate.

Unpublished cooling tests by Schomer [8] on cell-packed apples in fiberboard boxes indicate that the type of tray does not affect the cooling rate of the container when air can circulate around the container on all six sides. However, placing holes in the container ends did speed up the cooling rate.

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[6] See footnote 3.

[7] Schomer, H. A., and Patchen, G. O. Effects of Hydrocooling on the Dessert Quality and Storage Life of Apples in the Pacific Northwest. U.S. Dept. Agr., Agr. Res. Serv., ARS 51-24, 6pp., June 1968.

[8] Schomer, H. A., research plant physiologist, USDA, Wenatchee, Wash.

The research covered in this report agrees with the work of Guillou [9]
who stated that venting fiberboard boxes speeds cooling by exposing some of
the fruit surface inside the box to the cooling air. He used the rule of
thumb that with the removal of each 1 percent of the box surface the cooling
time is reduced about 5 percent.

[9] Guillou, Rene. Cooler for Fruits and Vegetables. Calif. Agr. Expt.
Sta. Bul. 773, July 1960.

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